Faculty of Mechanical Engineering

OPTIMIZATION OF A NATURAL ASPIRATED HYDROGEN DIESEL ENGINE

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OPTIMIZATION OF NATURAL ASPIRATED HYDROGEN DIESEL ENGINE

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DECLARATION

I declare that this thesis entitles "Optimization of A Natural Aspirated Hydrogen Diesel Engine" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :……………………………………..

Name :……………………………………..

Date :……………………………………….

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature	:……………………………………
Supervisor Name	:……………………………………
Date	:………………………………….…...

DEDICATION

To my beloved mother and father.

ABSTRACT

With the current level of awareness and increasing concerns surrounding climatic conditions, pollution and sustainability, hydrogen fuel has been the focus in providing clean energy for the combustion process engine by reducing emissions and improving engine performance. The primary objective of this project is to investigate the effect of hydrogen gas inside a diesel engine towards engine performance and emissions. The research process examines the hydrogen effect inside an unmodified diesel internal combustion engine, commencing with three different parameters, which are engine speed, hydraulic loading and the hydrogen supply rate. The first phase was run at the constant engine speed and hydraulic loading with a variable hydrogen rate. The second phase was executed using a fixed engine speed, but with variable hydraulic loading and variant hydrogen supply. Finally, the third phase was performed on the optimization of the hydrogen effect using the Taguchi method (L_9 arrays), signal noise (S/N) ratio, and analysis of variance (ANOVA) between 3 controlled factors and levels. The optimal combination of hydrogen inside the system was verified based on a confirmation test. The corresponding responses are brake power and brake specific fuel consumption. Also, the emissions responses are consisting of nitrogen oxide, hydrocarbon, carbon monoxide and carbon dioxide were investigated via a diesel test rig, hydrogen workstation, and an MRU gas analyser. Significant performance and emission outcomes were determined at the best optimization combinations at low engine speed with 4000 kPa hydraulic loading and hydrogen flow rate of 6 l/min. By comparing with the same condition, but without the addition of hydrogen or the original diesel baseline, the brake power increased by 1.93 % and the reduction of BSFC, CO_2, hydrocarbon, and CO to 29.67 %, 38.36 %, 18.21 %, 82.1 % respectively. Nevertheless, the nitrogen oxide emission increased to 552.15 ppm with the optimised condition from 280.512 ppm from the original diesel baseline.

ABSTRAK

Dengan tahap kesedaran semasa dan kebimbangan yang meningkat terhadap keadaan cuaca sekitaran, pencemaran dan kelestarian, bahan api hidrogen menjadi fokus dalam menyediakan tenaga bersih untuk proses pembakaran enjin dengan mengurangkan pelepasan dan meningkatkan prestasi enjin. Objektif utama projek ini adalah untuk mengkaji kesan gas hidrogen di dalam enjin diesel terhadap prestasi dan pelepasan enjin. Proses kajian menyelidik kesan hidrogen dalam pembakaran enjin diesel yang tidak diubahsuai dengan 3 parameter berbeza, iaitu kelajuan enjin, beban hidraulik dan kadar bekalan hidrogen. Fasa pertama dijalankan pada kelajuan enjin malar dan beban hidraulik dengan kadar hidrogen yang pelbagai. Fasa kedua dilaksanakan pada kelajuan enjin tetap dengan beban hidraulik dan kadar hidrogen yang pelbagai. Akhir sekali, fasa ketiga menggunakan kaedah Taguchi (L9 arrays), nisbah isyarat bunyi (S / N) dan analisis varians (ANOVA) bagi pengoptimuman kesan hidrogen dengan 3 faktor dan tahap yang terkawal. Kombinasi optimum hidrogen di dalam sistem ditentusahkan berdasarkan ujian pengesahan. Respon yang dikenal pasti ialah brek kuasa dan penggunaan bahan api brek spesifik. Selain itu, bahan pelepasan enjin yang terdiri daripada nitrogen oksida, hidrokarbon, karbon monoksida dan karbon dioksida dikaji melalui rig ujian diesel, stesen kerja hidrogen dan penganalisis gas MRU. Prestasi dan pelepasan enjin ditentukan pada kombinasi optimum yang terbaik iaitu kelajuan enjin rendah dengan beban hidraulik 4000kPa dan kadar aliran hidrogen sebanyak 6 l / min. Dengan membandingkan keadaan yang sama tetapi tanpa tambahan hidrogen atau garis rujukan diesel asal, kuasa brek meningkat sebanyak 1.93% dan pengurangan BSFC, karbon dioksida, hidrokarbon dan karbon monoksida yang masing-masing ialah 29.67%, 38.36%, 18.21% dan 82.1%. Walau bagaimanapun, pelepasan nitrogen oksida telah meningkat kepada 552.15ppm dengan keadaan yang optimum daripada 280.512ppm dari garis rujukan diesel asal.

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LIST OF SYMBOLS

^{o}CA	-	Crank angle
η_i	-	Indicated thermal efficiency
ϕ	-	Equivalence ratio
Q_A	-	Actual pump flow rate (m^3/min)
Q_T	-	Theoretical pump flow rate (m^3/min)
V_d	-	Volume displacement (m^3/rev)
P_p	-	Actual pump output power (W)
P	-	Hydraulic pressure inside pump (bar)
T_P	-	Actual torque delivered to the pump (Nm)
T_E	-	Actual torque delivered by the engine (Nm).
n	-	Speed ratio or radius ratio
P_E	-	Actual power delivered by the engine (W)
N	-	Pump speed (rpm)
$\dot{m}_{diesel}$	-	Mass flow rate of diesel (kg/s)
$\dot{m}_{hydrogen}$	-	Mass flow rate of hydrogen (kg/s)
LHV_{diesel}	-	Low heating value of diesel (kJ/kg)
$LHV_{hydrogen}$	-	Low heating value of hydrogen (kJ/kg).
y_i	-	Quality characteristic value taken from the trial

LIST OF ABBREVIATIONS

HC	-	Hydrocarbon
CO	-	Carbon monoxide
NO_X	-	Nitrogen oxide
CO_2	-	Carbon dioxide
O_2	-	Oxygen
CI	-	Compression ignition
PEM	-	Polymer electrolyte membrane
KOH	-	Potassium hydroxide
PV	-	Photovoltaic
SI	-	Spark ignition/ Gasoline engine/ Petrol engine
CR	-	Compression ratio
TMI	-	Timing manifold/ Port injection
DHI	-	Direct hydrogen injection
CMI	-	Continuous manifold induction
DDF	-	Diesel dual fuel
BTE	-	Brake thermal efficiency
BSFC	-	Brake specific energy consumption
EGR	-	Exhaust gas circulation
BTDC	-	Before top dead center

BMEP	-	Brake mean effective pressure
IMEP	-	Indicated mean effective pressure
Mpa	-	Megapascal
TDC	-	Top dead center
N_2	-	Nitrogen gas
ppm	-	Part per million
NH_3	-	Ammonia gas
LPG	-	Liquefied petroleum gas
CNG	-	Compressed natural gas
HCN	-	Hydrogen cyanide
S/ N	-	Signal to Noise
CRDI	-	Common Rail Direct Injection
DOE	-	Design of Experiment
CI	-	Confidence interval
ANOVA	-	Analysis of variance
ºCA	-	Crank angle

LIST OF PUBLICATIONS

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Energy is essential for sustaining the modern-day economy and is a key enabler for economic growth. The reasonable, accessible and ecologically friendly energy sources are equally important for future availability, economic and sustainability development. The main energy resources globally, consist of fossil fuels, renewable energy and nuclear energy. Likewise, petroleum oil, natural gas and coal are examples of fossil fuels, and examples of renewable energy are hydro, solar, wind, geothermal, combustible waste and marine energy (Diesel Forum, 2016). Also, the consumption of energy continues to grow with the advancement of technology, transportation and increasing population. Therefore, the demand for petroleum, natural gas and coal remain high. The reserves of fossil fuels rapidly dwindling over the years has contributed to the environmental concerns, such as reduction of the ozone layer, the greenhouse effect, acid rain and pollution. Thus, this chapter presents the background of study, problem statement, objectives, hypothesis, scope and research significant of this research.

1.2 Background of Study

The conventional hydrocarbon found in fossil fuels, release hydrocarbons (HC), carbon monoxide gases (CO), nitrogen oxide (NO_X), smoke emissions and other particulate matter into the atmosphere. Given these concerns, regulations on exhaust gas emissions have been urgently implemented and imposed with many researchers now exploring other alternative fuel sources, and to understand more about their performance, emissions and their combustive characteristics. Such alternative fuel sources include compressed natural gas (CNG), hydrogen, alcohols (methanol and ethanol), biogas, liquefied petroleum gas (LPG), biodiesels and others. Notably, alternative fuels are derived from other sources besides crude oil to reduce energy dependence, fewer pollutants and above all, to improve the air quality (Bockris et al., 1981; Bertrand, 2002; Ganesan, 1984). Interestingly, several experts in this field agree that hydrogen is likely, the best solution to our global problems by replacing existing sources or assisting in increasing the efficiency of existing fossil fuel systems. Clean fuel such as hydrogen maybe one of the solutions to alleviate the energy crisis, because it is ecologically-friendly (i.e. eco-friendly) and is a renewable energy source. Also, as an energy resource, hydrogen is diverse, and the potential for zero emission is significantly high due to the absence of carbon molecules found in hydrogen, therefore making it very efficient and recognised as a clean fuel (Kawahara et al., 2001).

1.3 Problem Statement

The diesel engine, or compression ignition (CI) engine, is an efficient internal combustion engine (ICE) compared with the gasoline engine. Moreover, this is because when the ignition in the engine occurs, the higher denser fuel is injected into the combustion chamber at an elevated (high) temperature thereby generating higher compression energy. However, the diesel engine also contributes to environmental pollution problems and emissions (Prasad and Bella, 2010). The incremental number of diesel vehicles each year has also added to more diesel gas emissions entering the atmosphere, resulting in adverse health implications for humanity and wildlife such as the development of cancer, cardiovascular conditions and respiration problems. Furthermore, diesel gas emissions contain hydrocarbon (HC), carbon monoxide (CO), nitrogen oxide (NO_X) and carbon dioxide (CO_2) (Ganesan, 2012). As a result, the level of environmental awareness surrounding these issues conducted in this study will help to investigate and provide alternative methods to reduce the amount and nature of emissions from diesel locomotives. For instance, introducing a low percentage of hydrogen into the air intake before combustion will decrease the level of emissions (and substances) from contributing to environmental problems and also to improve engine performance.

1.4 Objectives

The purpose of this study is to investigate the effect of hydrogen gas inside a diesel engine by applying the following objectives:

i. To compute the required volume of hydrogen gas to reduce the amount of emissions emitted by a compression ignition (Cl) / diesel engine; and
ii. To optimise the hydrogen additive supply for the optimal performance of the internal combustion (IC) engine and reduce emissions.

1.5 Hypothesis

The amount of HC, CO and CO_2 emissions are reduced far better than using regular diesel fuel in the exhaust gas at lower engine speeds when supplying hydrogen gas (Mirica et al., 2015; Kumar et al., 2015). The CO emission is formed at high combustion temperatures and with oxygen deficiency. Also, the improvement in engine performance, by respectively operating the speed of the motor at higher revolutions, and adding hydrogen gas into the system, will further decrease the amount of CO in the exhaust and reduce the amount of black carbon (soot). The effect is due to the hydrogen causing complete fuel burning to occur with fewer emissions. Notably, the minimum amount of NO_X in the exhaust gas occurs at low engine speeds.

1.6 Scope

Based on the objectives outlined earlier, the scope of this work is presented below.

i. The experimental investigation will be performed using a single cylinder diesel engine (KM-170) coupling with a hydraulic pump that acts as loading (0 – 4000 KPa).

ii. The hydrogen additions inside the diesel engine are limited from 0 l/min to 7 l/min to avoid severe damage occurring to the engine;

iii. The working data is used to optimise 'Design of Experiments' (DOE), and (Taguchi's method and ANOVA) for finding the best performance and emission with hydrogen addition

1.7 Research Significance

The current system within the automotive industry is based on using petroleum resources, mainly gasoline and diesel fuels. However, it is possible to upgrade and improve the system ecologically by applying several additives such as hydrogen gas without modifying the engines. For example, by adding 2 l/min of hydrogen, it is possible to increase brake power by 1.4 %, which reduces fuel consumption by 9.8 % and the emissions of carbon monoxide (CO) by 12 %, hydrocarbon (HC) by 8.3 %, and carbon dioxide (CO2) by 8.3 %. Furthermore, understanding the application of hydrogen into the engine will further assist to promote this 'green innovative' approach within the community and will create